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Nutrients and Dissolved Oxygen in Maine Estuaries and Embayments, Final Data Report to New England Interstate Water Pollution Control Commission (NEIWPCC)

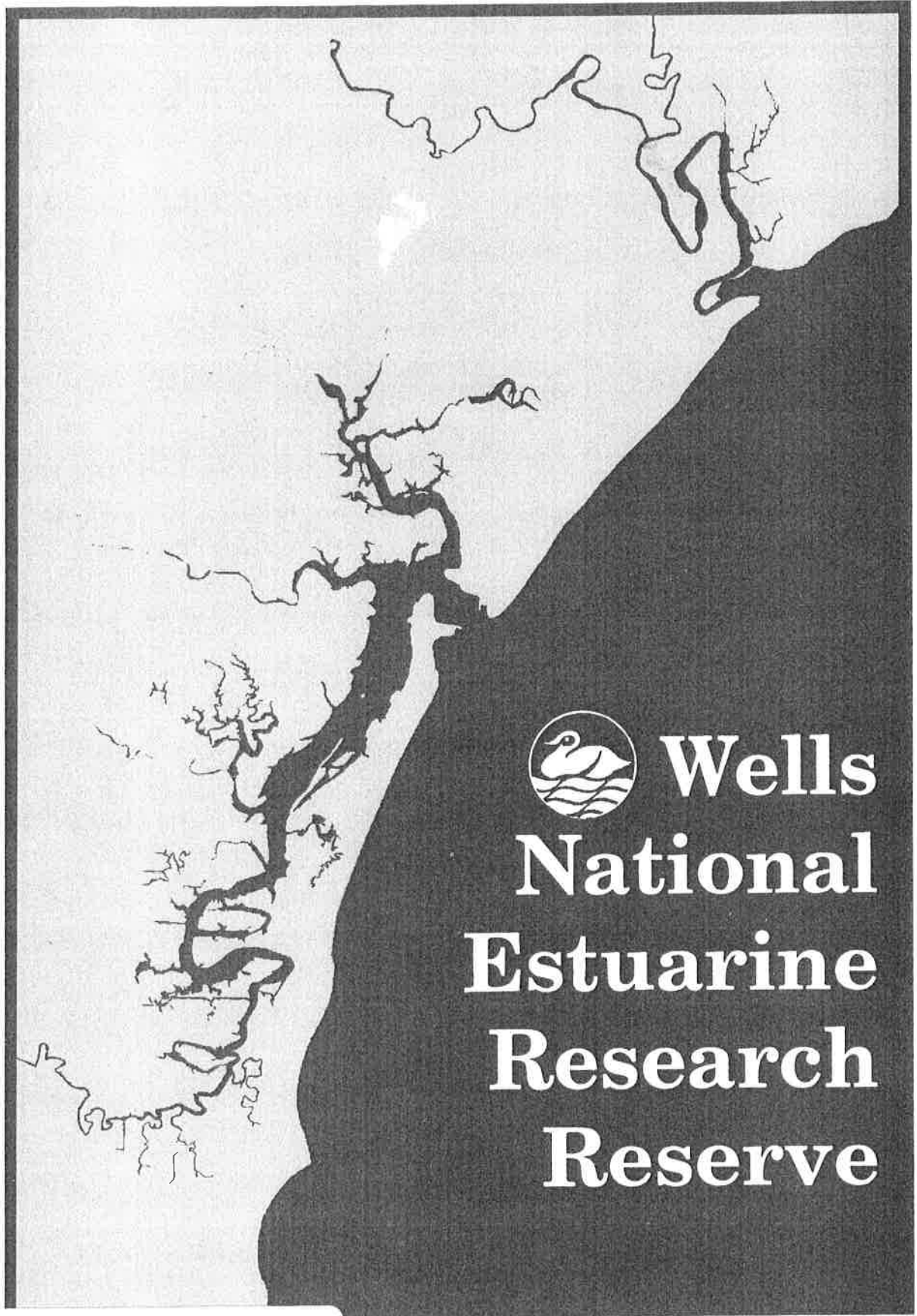
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 **Wells
National
Estuarine
Research
Reserve**

Nutrients and Dissolved Oxygen in Maine Estuaries and Embayments

Final Data Report

Submitted by

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Submitted to the

* New England Interstate Water Pollution Control Commission
255 Ballardvale Street
Wilmington, MA 01877

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Introduction

The 5200 mile long coastline of Maine is a highly indented margin between land and sea composed of hundreds of estuaries and embayments. Maine's coastal intertidal and subtidal habitats are extremely varied, with 22 habitat types recently identified for intertidal areas alone, ranging from mudflats to salt marsh to ledge (Brown 1993). These habitats are flushed twice daily by 7 to 22 foot high tides of relatively nutrient rich waters from the Gulf of Maine. The State Planning Office, the Department of Environmental Protection, and the Wells National Estuarine Research Reserve have developed an approach to managing non-point source pollution that is appropriate for the length, complexity, flushing rates and uneven distribution of human impacts that make Maine's coastline unique (Heinig 1993).

Non-point source pollution has the potential to degrade the quality of coastal waters through the input of excess nutrients, especially nitrogen. It is well established for the estuarine waters of the Chesapeake Bay that excess nitrogen from anthropogenic sources fuels high levels of phytoplankton productivity during the warmer months (see Malone et al. 1993 for review). Much of the phytoplankton biomass settles to the bottom uneaten by zooplankton or shellfish. This accumulated organic matter creates a high biological oxygen demand when it is consumed through aerobic respiration by microbes and benthic invertebrates. As water temperature increases through the spring and summer, so does respiration. Density stratification prevents the bottom waters of the Bay from mixing with the well oxygenated surface waters. The result is increasingly hypoxic conditions in large volumes of Bay water, unsuitable for many species of fish and invertebrates (Officer 1983; Malone et al. 1992; Malone et al. 1993; Kemp et al. 1994). This extensive research linking excess nitrogen from human sources to oxygen depletion provides by far the best example of the negative effects of nutrient enrichment in a coastal ecosystem. It points to dissolved oxygen depression as the best known indicator of coastal nutrient enrichment.

Prior to 1995, very little was known about the impact of nutrient enrichment on Maine's coastal waters (Heinig 1994). Through a series of meetings with regional experts, an approach to nutrient enrichment assessment was developed, using dissolved oxygen as an indicator of nutrient enrichment. Dissolved oxygen (DO) was selected as an indicator of nutrient enrichment, because dissolved oxygen levels typically decline when high primary productivity creates a high biological oxygen demand in a water body (see previous paragraph). The goal of the program developed is to produce a model of nutrient enrichment susceptibility appropriate for Maine's coastal waters. This model will be used

to target coastal water bodies for special planning and protection measures to prevent the negative effects of nutrient enrichment.

Results from 1995 Survey and Modelling

The first step in the program was to determine the extent of coastal nutrient enrichment in Maine. In 1995, dissolved oxygen profiles were measured in 19 estuaries and embayments from southwestern to eastern Maine. The study sites were selected to provide a range of susceptibility to nutrient enrichment. Profiles were measured monthly from July to September for each system, along linear transects from inlet to head of tide. The primary results of the survey were (Kelly and Libby 1996a; Kelly and Libby 1996b):

- Dissolved oxygen depression ($DO < 7$ mg/l; DO saturation $< 80\%$) occurred infrequently in most estuaries, due to high tidal flushing
- Only a few estuaries experienced $DO < 6$ mg/l; only one regularly
- Dissolved oxygen levels were lowest in bottom waters in September
- Density stratification explained about 25% of the observed variation in DO
- In our dissolved oxygen model, 84% of the variation in DO was explained by the following 3 variables:
 - relative freshwater discharge
 - tidal range
 - water temperature
- Flushing characteristics alone do not explain DO behavior in systems experiencing DO depression

An important caveat to the results of the survey is that the 1995 sampling season was unusually dry. Freshwater discharge into coastal waters was well below the average. The dissolved oxygen dynamics observed may be atypical, especially in light of the fact that our model predicts lower DO with higher relative freshwater discharge.

Once properly tested (see below), the dissolved oxygen model can be used to predict dissolved oxygen levels based on relative freshwater discharge, tidal range, and water temperature. This model could be used to predict conditions under which a coastal water body would experience depressed oxygen levels - in essence, a **depressed oxygen susceptibility model**.

In 1996, we continued to investigate dissolved oxygen dynamics in Maine coastal waters. Our objectives were:

- 1) Repeat 1995 sampling on selected water bodies to determine year to year variation in DO
- 2) Select new water bodies with high relative freshwater discharge (RFD) to test the model developed in 1995 that predicted DO from RFD, tidal range and water temperature.

- 3) Conduct more detailed study of DO behavior and potential explanatory factors in systems experiencing the greatest oxygen depression in 1995

Methods

Study Sites

Sixteen water bodies were sampled in 1996, representing much of the Maine coast, from the southwestern corner (Spruce Creek in Kittery) to downeast Maine (Taunton Bay adjoining Frenchman's Bay near Mt. Desert Island). These water bodies were selected to represent a range of nutrient loading and tidal flushing conditions (Table 1). Combinations of high loading-high flushing, low loading-high flushing, high loading-low flushing, and low loading-low flushing were included. For each water body, sampling stations were selected in a transect from inlet to head of tide. The number of stations varied from 2 to 6 depending on the size of the water body.

Annual Variation in Dissolved Oxygen

We measured dissolved oxygen profiles in six of the 19 water bodies surveyed in 1995, following the 1995 sampling design. The water bodies were selected from each coastal region - three in Southwestern Maine, two in Casco Bay, and one in Down East Maine. We will compare dissolved oxygen dynamics from 1996 to that in 1995. This will indicate how variable or consistent oxygen levels in these waters can be in two consecutive years. Without information on annual variation, we cannot properly interpret the results of the 1995 study. . We followed the same sampling procedures used in 1995 - measuring dissolved oxygen at 1 ft depth intervals at 4 to 10 stations from inlet to head of tide, using YSI 6000 datasondes. Other parameters measured at each depth were: **salinity, water temperature, and specific conductivity**. The datasondes generated **dissolved oxygen percent saturation** from an algorithm based on absolute dissolved oxygen, temperature and salinity. From 1995, we knew that dissolved oxygen was at its lowest level in September, so water bodies were sampled in August and September, on early morning low tides.

When additional funds are available, we hope to broaden our view of annual variation in dissolved oxygen, by analyzing historical dissolved oxygen data at 15 Casco Bay sites, including 4 of the sites sampled in our 1995 survey. These data have been collected by the Friends of Casco Bay since 1993, using methods compatible with the methods in our study.

Relative Freshwater Discharge

A major result of the 1995 study was a model explaining dissolved oxygen levels in the 19 surveyed water bodies. Systems were selected on the basis of tidal flushing and nutrient

loading. Variation in freshwater discharge between systems was held to a minimum, so as not to confound the effect of tidal flushing. Surprisingly, in the results of the 1995 survey, relative freshwater discharge (the amount of freshwater input relative to the tidal volume of the estuary) was found to be an important predictor of dissolved oxygen. This result was due in large part to the behavior of a single water body (Little River in Wells), that had higher relative discharge than the other systems.

In order to test the validity of the model as a predictive tool, we collected data from a new suite of water bodies that vary in relative freshwater discharge. Actual dissolved oxygen levels will be compared to those predicted by the 1995 model.

Nutrient Loading

In the dissolved oxygen model described above, relative freshwater discharge was used as a proxy for nutrient loading. To increase the ability of the model to explain patterns in dissolved oxygen, we measured nutrient concentrations at dissolved oxygen sampling stations. Adding nutrient parameters will increase the model's ability to reflect the hypothesized mechanisms that influence dissolved oxygen dynamics. Nutrient species measured were: **particulate carbon (PC), particulate nitrogen (PN), dissolved inorganic nitrogen (DIN), nitrate+nitrite ($\text{NO}_2 + \text{NO}_3$), ammonium (NH_4), total dissolved nitrogen (TDN), dissolved organic nitrogen (DON), orthophosphate (PO_4), total dissolved phosphorous (TDP), dissolved organic phosphorous (DOP). Chlorophyll a**, an index of phytoplankton standing stock, was also measured. The nutrient data will be used to transform the oxygen depression susceptibility model into a **nutrient enrichment susceptibility model**. In this model, oxygen levels will be predicted from nutrient levels and other parameters. The modelling portion of this project is being funded by the Maine State Planning Office, and will be completed by 30 June 1997.

Whole water samples were collected at the surface (1 ft depth) at all dissolved oxygen (DO) sampling stations. At stations where the DO/temperature profiles indicated stratification, water samples were also collected 1 foot from the bottom. Water was collected with a 2 liter van Dorn bottle, using a messenger to collect water at the desired level. Water was then drawn off for chlorophyll and nutrient measurement.

Chlorophyll a

A 500 ml sample was placed in a polyethylene container rinsed twice in ambient water. Samples were placed immediately on ice in the dark and filtered the same day (buffered with MgCO_3) in the laboratory. Filters were wrapped in glassine envelopes and frozen for analysis using procedures outlined in the project Quality Assurance Project Plan (QAPP-sent under separate cover).

Dissolved Nitrogen and Phosphorous

A 60 ml syringe was rinsed twice with water from the van Dorn bottle, then 60 ml aliquots were passed through a pre-combusted and pre-weighed Whatman GF/F filter (this was done twice for each sample - one sample for inorganic N and P, the other for total dissolved N). At least 35 mls of each 60 ml filtrate sample was stored in an acid washed vial, put on ice and kept in the dark. On each sampling day, three blank samples (120 mls each) were filtered using deionized water to detect contamination introduced during the sampling procedure. After each sample, syringe, and filter holder were rinsed with deionized water. Filters were handled with forceps, which were also rinsed in deionized water after each sample. Samples were frozen upon return to the lab, and analyzed according to the procedures outlined in the QAPP.

Particulate Carbon and Nitrogen

Filters used to collect particles from the dissolved nutrient samples (above) were folded in half and wrapped in pre-combusted and pre-weighed foil wrappers, and put on ice in the dark. Forceps were used to handle filters and foil. On each sampling date, three blanks were made using deionized water rather than sample water, to determine the amount of particulate contamination on the filters from the atmosphere. The average of these blanks was then subtracted from the values of the samples on those days. Samples were frozen upon return to the lab, and analyzed according to the procedures outlined in the QAPP.

Results

The complete data for dissolved oxygen, nutrients and chlorophyll, along with other physico-chemical parameters are presented in Appendix 1. Data are presented for each water body sampled, with sampling stations in ascending order from inlet to head of tide. Morphometric characteristics of each system studied are presented in Appendix 2.

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Table 1. Water Bodies Sampled in 1996*

<u>Water Bodies</u>	<u>Water Bodies Also Sampled in 1995</u>	<u>Water Bodies Only Sampled in 1996</u>
Taunton Bay (TAUN)	Taunton Bay	
Belfast Bay (BELF)		Belfast Bay
St. George River (STGE)		St. George River
John's Bay/ John's River (JOHN)		John's Bay/ John's River
Damariscotta River (DAMA)		Damariscotta River
Quahog Bay (QHBY)	Quahog Bay	
Maquoit Bay (MAQB)	Maquoit Bay	
Harraseeket River (HARR)	Harraseeket River	
Cousins River (COUS)		Cousins River
Spurwink River (SPWK)		Spurwink River
Batson River (BATS)		Batson River
Kennebunk River (KENN)		Kennebunk River
Little River (LITT)	Little River	
Webhannet River (WEBH)		Webhannet River
York River (YORK)		York River
Spruce Creek (SPRU)	Spruce Creek	

*(in order from east to west)

APPENDIX 1

Dissolved Oxygen, Nutrient and Chlorophyll Data

Abbreviations for column headings should be obvious from text and table except in the following cases:

SpCond is specific conductivity

adj is abbreviation for adjusted (i.e. corrected for background levels found on blanks

N+N is abbreviation for $\text{NO}_2 + \text{NO}_3$

System	Station #	Date	Time	Depth ft	Depth Meters	Temp C	Sal ppt	DO mg/L	DO %	SpCond mS/cm	adj PC (mg/l)	adj PN (mg/l)	Chl a (µg/l)	# days over	Depth Meters	DIN (µM)	N+N (µM)	NH4 (µM)	PO4 (µM)	TDN (µM)	TDP (µM)	DON (µM)	DOP (µM)	
DAMA	4	8/19/96	6:01:37	6.50	1.97	18.50	31.10	8.02	103.00	47.70					1.97									
DAMA	4	8/19/96	6:02:17	0.90	0.27	18.80	31.30	8.00	103.50	47.89					0.27									
DAMA	5	9/12/96	10:35:26	0.10	0.03	20.00	31.20	6.69	88.40		0.1913	-0.0320	1.42	0	0.03	4.54	1.48	3.06	1.30	16.32	1.34	11.78	0.04	
DAMA	5	9/12/96	10:36:22	22.20	6.73	19.50	31.50	6.51	85.50						6.73									
DAMA	5	9/12/96	10:36:42	19.00	5.76	19.50	31.50	6.55	86.10						5.76									
DAMA	5	9/12/96	10:36:58	15.80	4.79	19.60	31.50	6.56	86.20						4.79									
DAMA	5	9/12/96	10:37:18	12.60	3.82	19.70	31.40	6.65	87.50						3.82									
DAMA	5	9/12/96	10:37:34	9.40	2.85	19.90	31.30	6.64	87.50						2.85									
DAMA	5	9/12/96	10:37:42	9.40	2.85	19.80	31.30	6.64	87.50						2.85									
DAMA	5	9/12/96	10:37:46	5.90	1.79	19.80	31.30	6.64	87.50						1.79									
DAMA	5	9/12/96	10:37:50	5.90	1.79	19.90	31.30	6.63	87.40						1.79									
DAMA	5	9/12/96	10:38:14	2.70	0.82	20.10	31.20	6.53	86.40						0.82									
DAMA	5	9/12/96	10:38:38	0.40	0.12	20.20	31.10	6.46	85.60						0.12									
DAMA	5	9/12/96	10:38:42	0.40	0.12	20.20	31.10	6.45	85.50						0.12									
DAMA	5	9/12/96	10:39:30	0.40	0.12	20.10	30.80	6.48	85.60						0.12									
DAMA	5	8/12/96	6:13:06	0.20	0.06	22.40	29.50	6.93	94.80		0.2676	0.0526	1.21	0	0.06	2.58	0.59	1.99	1.08	17.39	1.57	14.81	0.49	
DAMA	5	8/12/96	6:14:50	9.90	3.00	22.50	29.50	6.92	94.70						3.00					18.93	1.73			
DAMA	5	8/12/96	6:15:22	6.10	1.85	22.50	29.50	6.92	94.70						1.85									
DAMA	5	8/12/96	6:15:50	3.50	1.06	22.50	29.50	6.92	94.70						1.06									
DAMA	5	8/12/96	6:16:34	0.20	0.06	22.50	29.50	6.91	94.50						0.06									
DAMA	5	8/19/96	8:04:02	0.00	0.00								2.60	0	0.00									
HARR	1	8/15/96	8:05:02	3.60	1.09	17.60	30.80	8.09	102.00	47.26	0.3340	0.0789	1.64	0	0.15	1.65	0.44	1.21	0.68	14.60	0.69	12.95	0.01	
HARR	1	8/15/96	8:05:26	7.00	2.12	17.70	30.80	8.09	102.10	47.19					2.12									
HARR	1	8/15/96	8:06:14	13.50	4.09	17.60	30.80	8.01	101.00	47.26					4.09									
HARR	1	8/15/96	8:06:54	19.60	5.94	17.60	30.80	8.03	101.30	47.26					5.94									
HARR	1	8/15/96	8:07:26	27.00	8.18	17.50	30.90	8.00	100.70	47.40					8.18									
HARR	1	8/15/96	8:08:06	32.80	9.94	17.30	31.00	7.85	98.50	47.55					9.94									
HARR	1	8/15/96	8:08:50	39.80	12.06	16.90	30.90	7.84	97.70	47.44					12.06									
HARR	1	8/15/96	8:09:34	46.20	14.00	15.80	31.00	7.58	92.30	47.57					14.00									
HARR	1	8/15/96	8:09:54	50.20	15.21	15.50	30.80	7.54	91.20	47.31	0.2135	0.0461	1.26	0	15.21	2.85	0.97	1.88	0.71	10.05	0.81	7.20	0.10	
HARR	1	9/17/96	6:44:09	3.30	1.00	15.50	31.70	7.44	90.50	48.48	0.2196	0.0259	1.48	0	1.00	5.22	1.13	4.09	1.16	12.83	1.24	7.61	0.08	
HARR	1	9/17/96	6:44:49	6.70	2.03	15.50	31.70	7.49	91.10	48.48					2.03									
HARR	1	9/17/96	6:45:29	13.10	3.97	15.50	31.70	7.32	89.10	48.48					3.97									
HARR	1	9/17/96	6:46:09	19.60	5.94	15.50	31.70	7.20	87.60	48.48					5.94									
HARR	1	9/17/96	6:46:45	26.30	7.97	15.50	31.70	7.20	87.60	48.48					7.97									
HARR	1	9/17/96	6:47:29	32.70	9.91	15.50	31.70	7.20	87.60	48.48					9.91									
HARR	1	9/17/96	6:48:05	39.50	11.97	15.50	31.70	7.21	87.80	48.48					11.97									
HARR	1	9/17/96	6:48:21	41.90	12.70	15.50	31.70	7.19	87.50	48.48					12.70									
HARR	2	8/15/96	7:10:53	0.20	0.06	18.10	30.80	7.50	95.50	47.23	0.2683	0.0505	1.44	0	0.06	3.52	0.74	2.78	1.00	17.04	1.20	13.52	0.20	
HARR	2	8/15/96	7:11:41	3.00	0.91	18.10	30.80	7.51	95.70	47.23					0.91									
HARR	2	8/15/96	7:12:13	7.00	2.12	18.10	30.80	7.52	95.80	47.23					2.12									
HARR	2	8/15/96	7:13:37	12.80	3.88	17.90	31.00	7.45	94.40	47.51					3.88									
HARR	2	8/15/96	7:14:05	17.80	5.39	17.30	31.00	7.53	94.50	47.55	0.3608	0.0428	1.05	0	5.39	2.91	0.70	2.21	0.76	14.87	1.05	11.95	0.29	
HARR	2	9/17/96	7:15:47	0.10	0.03	15.60	31.20	7.39	89.80	47.82	0.2571	0.0308	1.14	0	0.03	6.05	1.23	4.82	1.31	15.61	1.51	9.55	0.20	
HARR	2	9/17/96	7:16:27	3.20	0.97	15.60	31.20	7.31	88.50	47.82					0.97									
HARR	2	9/17/96	7:16:59	13.30	4.03	15.50	31.20	7.26	88.10	47.90					4.03									
HARR	2	9/17/96	7:17:19	18.50	5.61	15.50	31.20	7.23	87.80	47.90					5.61									
HARR	3	8/15/96	6:24:50	0.20	0.06	18.90	30.20	7.19	92.60	46.42	0.2723	0.0760	1.44	0	0.06	3.91	1.00	2.92	1.18	19.45	1.33	15.54	0.14	

System	Station #	Date	Time	Depth ft	Depth Meters	Temp C	Sal ppt	DO mg/L	DO %	SpCond mS/cm	adj PC (mg/l)	adj PN (mg/l)	Chl a (µg/l)	# days over	Depth Meters	DIN (µM)	N+N (µM)	NH4 (µM)	PO4 (µM)	TDN (µM)	TDP (µM)	DON (µM)	DOP (µM)
KENN	1	8/15/96	6:05:50	1.00	0.30	15.54	29.80	7.99	96.20	45.95					0.30								
KENN	1	8/15/96	6:06:13	1.01	0.31	15.56	29.80	7.99	96.20	45.91					0.31								
KENN	1	8/15/96	6:06:52	0.53	0.16	15.59	29.80	7.98	96.20	45.86					0.16								
KENN	1	8/15/96	6:06:59	0.53	0.16	15.59	29.80	7.98	96.20	45.86					0.16								
KENN	1	8/15/96	6:07:09	0.53	0.16	15.59	29.80	7.98	96.20	45.85					0.16								
KENN	1	8/15/96	6:07:27	0.53	0.16	15.59	29.80	7.98	96.20	45.85					0.16								
KENN	1	8/15/96	6:07:59	0.07	0.02	15.60	29.80	7.98	96.20	45.83					0.02								
KENN	1	8/15/96	6:08:08	0.07	0.02	15.60	29.70	7.99	96.30	45.83					0.02								
KENN	1	8/15/96	6:08:15	0.07	0.02	15.60	29.70	7.99	96.30	45.81					0.02								
KENN	1	9/13/96	5:42:16	0.08	0.02	16.40	31.40	6.97	86.20	48.10	0.1404	0.0852	1.00	0	0.02	4.14	1.05	3.10	0.72	26.93	0.95	22.78	0.23
KENN	1	9/13/96	5:43:03	0.10	0.03	16.40	31.40	6.89	85.20	48.08					0.03								
KENN	1	9/13/96	5:44:02	0.09	0.03	16.41	31.40	6.84	84.60	48.09					0.03								
KENN	1	9/13/96	5:45:50	2.53	0.77	16.42	31.40	6.78	83.90	48.15	0.0876	0.0231	0.96	0	0.77	4.10	1.10	2.99	0.73	20.21	0.93	16.12	0.20
KENN	1	9/13/96	5:46:23	2.50	0.76	16.42	31.40	6.78	83.90	48.14					0.76								
KENN	1	9/13/96	5:46:57	2.56	0.78	16.42	31.40	6.77	83.80	48.14					0.78								
KENN	1	9/13/96	5:48:16	1.52	0.46	16.42	31.40	6.75	83.60	48.12					0.46								
KENN	1	9/13/96	5:49:02	1.52	0.46	16.42	31.40	6.75	83.60	48.13					0.46								
KENN	1	9/13/96	5:49:41	1.49	0.45	16.42	31.40	6.75	83.50	48.12					0.45								
KENN	1	9/13/96	5:50:39	0.53	0.16	16.41	31.40	6.75	83.50	48.10					0.16								
KENN	1	9/13/96	5:51:12	0.53	0.16	16.41	31.40	6.75	83.50	48.10					0.16								
KENN	1	9/13/96	5:51:41	0.52	0.16	16.41	31.40	6.74	83.40	48.11					0.16								
KENN	1	9/13/96	5:52:20	0.09	0.03	16.41	31.40	6.74	83.40	48.09					0.03								
KENN	1	9/13/96	5:52:49	0.09	0.03	16.40	31.40	6.74	83.40	48.09					0.03								
KENN	1	9/13/96	5:53:17	0.10	0.03	16.40	31.40	6.74	83.40	48.08					0.03								
KENN	2	8/15/96	6:43:23	0.12	0.04	17.37	26.80	7.68	94.20	41.68	0.2837	0.0465	0.97	0	0.04	4.34	1.50	2.84	0.64	16.68	0.76	12.34	0.11
KENN	2	8/15/96	6:45:05	0.04	0.01	17.41	26.70	7.71	94.50	41.51					0.01								
KENN	2	8/15/96	6:45:17	0.04	0.01	17.42	26.60	7.70	94.40	41.47					0.01								
KENN	2	8/15/96	6:48:18	2.63	0.80	17.30	27.00	7.64	93.60	41.94	0.3283	0.0767	1.10	0	0.80	4.42	1.36	3.07	0.63	14.84	0.78	10.42	0.15
KENN	2	8/15/96	6:48:25	2.63	0.80	17.30	27.00	7.63	93.50	41.95					0.80								
KENN	2	8/15/96	6:48:32	2.63	0.80	17.30	27.00	7.63	93.50	41.96					0.80								
KENN	2	8/15/96	6:49:39	2.51	0.76	17.30	26.90	7.61	93.20	41.91					0.76								
KENN	2	8/15/96	6:49:49	2.51	0.76	17.30	26.90	7.60	93.10	41.91					0.76								
KENN	2	8/15/96	6:49:57	2.51	0.76	17.30	26.90	7.59	93.00	41.91					0.76								
KENN	2	8/15/96	6:51:17	2.01	0.61	17.30	26.90	7.60	93.10	41.87					0.61								
KENN	2	8/15/96	6:51:24	2.01	0.61	17.30	26.90	7.60	93.10	41.88					0.61								
KENN	2	8/15/96	6:51:31	2.01	0.61	17.30	26.90	7.60	93.10	41.89					0.61								
KENN	2	8/15/96	6:53:19	1.00	0.30	17.43	26.60	7.64	93.70	41.39					0.30								
KENN	2	8/15/96	6:53:26	1.00	0.30	17.44	26.60	7.64	93.70	41.38					0.30								
KENN	2	8/15/96	6:53:32	1.00	0.30	17.44	26.50	7.65	93.80	41.37					0.30								
KENN	2	8/15/96	6:56:02	0.51	0.15	17.44	26.50	7.66	93.90	41.38					0.15								
KENN	2	8/15/96	6:56:09	0.50	0.15	17.44	26.50	7.66	93.90	41.36					0.15								
KENN	2	8/15/96	6:56:29	0.50	0.15	17.45	26.50	7.66	93.90	41.34					0.15								
KENN	2	8/15/96	6:57:21	0.06	0.02	17.45	26.50	7.66	93.90	41.23					0.02								
KENN	2	8/15/96	6:57:33	0.06	0.02	17.45	26.50	7.66	93.90	41.25					0.02								
KENN	2	8/15/96	6:57:40	0.06	0.02	17.45	26.50	7.66	93.90	41.25					0.02								
KENN	2	9/13/96	6:21:34	0.03	0.01	16.84	29.90	6.69	82.70	46.01	0.0982	0.0231	1.18	0	0.01						18.94	1.02	
KENN	2	9/13/96	6:22:37	0.04	0.01	16.86	29.90	6.57	81.30	46.03					0.01								
KENN	2	9/13/96	6:24:34	2.71	0.82	16.85	30.00	6.45	79.80	46.17					0.82								
KENN	2	9/13/96	6:25:11	2.88	0.87	16.85	30.00	6.44	79.70	46.19	0.3683	0.0247	1.02	0	0.87	4.75	1.56	3.20	0.84	18.27	0.98	13.52	0.14

1996 Final NAP Data

System	Station #	Date	Time	Depth	Depth	Temp	Sal	DO	DO	SpCond	adj PC	adj PN	Chl a	# days	Depth	DIN	N+N	NH4	PO4	TDN	TDP	DON	DOP
				ft	Meters	C	ppt	mg/L	%	mS/cm	(mg/l)	(mg/l)	(µg/l)	over	Meters	(µM)	(µM)	(µM)	(µM)	(µM)	(µM)	(µM)	(µM)
WEBH	2	8/12/96	7:22:41	0.98	0.30	15.07	31.00	8.52	102.40	47.56					0.30								
WEBH	2	8/12/96	7:23:43	0.51	0.15	15.04	31.00	8.54	102.60	47.57					0.15								
WEBH	2	8/12/96	7:23:51	0.50	0.15	15.04	31.00	8.54	102.60	47.58					0.15								
WEBH	2	8/12/96	7:23:59	0.51	0.15	15.05	31.00	8.54	102.60	47.57					0.15								
WEBH	2	8/12/96	7:25:21	0.03	0.01	15.06	31.00	8.54	102.60	47.56					0.01								
WEBH	2	8/12/96	7:25:25	0.03	0.01	15.06	31.00	8.54	102.60	47.56					0.01								
WEBH	2	8/12/96	7:25:32	0.03	0.01	15.05	31.00	8.53	102.50	47.57					0.01								
WEBH	2	8/12/96	7:25:38	0.03	0.01	15.05	31.00	8.53	102.50	47.57					0.01								
WEBH	2	9/10/96	4:26:53	0.10	0.03	18.17	30.20	6.15	78.20	46.38	0.5958	0.0671	1.32	0	0.03	3.75	1.12	2.63	0.57	45.59	0.73	41.85	0.16
WEBH	2	9/10/96	4:31:20	0.05	0.01	18.05	30.10	5.85	74.20	46.26					0.01								
WEBH	2	9/10/96	4:32:36	0.05	0.01	18.05	30.00	5.78	73.20	46.22					0.01								
WEBH	2	9/10/96	4:35:08	1.49	0.45	17.95	30.40	6.02	76.30	46.75	0.4891	0.0829	1.40	0	0.45	3.27	0.78	2.48	0.59	24.87	0.89	21.61	0.30
WEBH	2	9/10/96	4:36:04	1.50	0.45	17.94	30.50	6.01	76.10	46.77					0.45								
WEBH	2	9/10/96	4:37:07	1.50	0.45	17.93	30.50	6.01	76.10	46.77					0.45								
WEBH	2	9/10/96	4:38:29	1.01	0.31	17.97	30.40	6.05	76.70	46.72					0.45								
WEBH	2	9/10/96	4:39:08	1.00	0.30	17.95	30.40	6.07	76.90	46.75					0.30								
WEBH	2	9/10/96	4:40:00	1.00	0.30	17.95	30.40	6.08	77.00	46.75					0.30								
WEBH	2	9/10/96	4:41:08	0.50	0.15	18.07	30.30	6.07	77.10	46.56					0.15								
WEBH	2	9/10/96	4:41:46	0.50	0.15	18.08	30.30	6.08	77.20	46.54					0.15								
WEBH	2	9/10/96	4:42:27	0.51	0.15	18.08	30.30	6.09	77.30	46.54					0.15								
WEBH	2	9/10/96	4:44:11	0.02	0.01	18.05	30.10	5.91	74.90	46.28					0.01								
WEBH	2	9/10/96	4:44:46	0.02	0.00	18.05	30.10	5.83	73.90	46.26					0.00								
WEBH	2	9/10/96	4:45:37	0.05	0.01	18.04	30.10	5.79	73.30	46.26					0.01								
WEBH	3	8/12/96	6:46:56	0.19	0.06	18.32	29.20	6.87	87.00	45.07	0.4379	0.0881	2.64	3	0.06	1.73	0.50	1.23	0.31	17.64	0.57	15.92	0.25
WEBH	3	8/12/96	6:48:31	0.10	0.03	18.24	29.20	6.84	86.50	45.03					0.03								
WEBH	3	8/12/96	6:48:38	0.10	0.03	18.22	29.20	6.84	86.50	45.04					0.03								
WEBH	3	8/12/96	6:48:47	0.10	0.03	18.20	29.20	6.83	86.40	45.04					0.03								
WEBH	3	8/12/96	6:49:42	0.54	0.16	18.18	29.20	6.80	85.90	45.05					0.16								
WEBH	3	8/12/96	6:49:52	0.54	0.16	18.17	29.20	6.79	85.80	45.04					0.16								
WEBH	3	8/12/96	6:50:02	0.55	0.17	18.17	29.20	6.78	85.70	45.05					0.17								
WEBH	3	8/12/96	6:51:10	0.14	0.04	18.15	29.20	6.77	85.50	45.06					0.04								
WEBH	3	8/12/96	6:51:24	0.15	0.05	18.15	29.20	6.77	85.50	45.07					0.05								
WEBH	3	8/12/96	6:51:31	0.15	0.05	18.16	29.20	6.77	85.50	45.06					0.05								
WEBH	3	8/12/96	6:52:06	0.07	0.02	18.15	29.20	6.78	85.60	45.08					0.02								
WEBH	3	8/12/96	6:52:14	0.07	0.02	18.16	29.20	6.78	85.60	45.08					0.02								
WEBH	3	8/12/96	6:52:20	0.07	0.02	18.16	29.20	6.78	85.60	45.08					0.02								
WEBH	3	9/10/96	5:25:14	0.07	0.02	18.15	29.90	6.05	76.80	46.11	0.5433	0.1930	1.86	0	0.02	3.69	1.00	2.69	0.59	29.33	0.93	25.64	0.34
WEBH	3	9/10/96	5:25:26	0.13	0.04	18.16	30.00	7.31	92.80	46.16					0.04								
WEBH	3	9/10/96	5:26:09	0.05	0.01	18.17	30.00	5.98	75.90	46.15					0.01								
WEBH	3	9/10/96	5:27:54	0.53	0.16	18.18	30.00	5.90	74.90	46.16					0.16								
WEBH	3	9/10/96	5:29:59	0.54	0.16	18.17	30.00	5.86	74.40	46.20					0.16								
WEBH	3	9/10/96	5:30:50	0.58	0.17	18.17	30.00	5.84	74.20	46.20					0.17								
WEBH	3	9/10/96	5:31:39	0.06	0.02	18.17	30.00	5.83	74.00	46.21					0.02								
WEBH	3	9/10/96	5:32:23	0.07	0.02	18.17	30.00	5.83	74.00	46.22					0.02								
WEBH	3	9/10/96	5:33:04	0.07	0.02	18.18	30.00	5.84	74.20	46.21					0.02								
YORK	1	8/14/96	5:47:52	0.11	0.03	15.39	29.90	8.21	98.60	46.01	0.2439	0.0264	0.64	1	0.03	1.95	0.39	1.55	0.53	10.99	0.66	9.05	0.13
YORK	1	8/14/96	5:48:58	0.11	0.03	15.45	29.80	8.23	98.90	45.98					0.03								
YORK	1	8/14/96	5:49:08	0.11	0.03	15.46	29.80	8.22	98.80	45.98					0.03								
YORK	1	8/14/96	5:49:15	0.11	0.03	15.49	29.80	8.20	98.70	45.96					0.03								
YORK	1	8/14/96	5:51:00	3.39	1.03	15.53	29.80	8.15	98.10	45.95	0.4173	0.0358	0.79	1	1.03	2.10	0.40	1.71	0.53	11.21	0.69	9.11	0.16

APPENDIX 2

Morphometric Characteristics of Selected Water Bodies

Water bodies presented in ascending order from southwest to northeast. Systems sampled in 1996 survey are highlighted in bold print.

Waterbody (n=55)	Region	HW Area (km ²)	CD Area (km ²)	HW Volume (millions m ³)	Tidal Volume (millions m ³)	Flushing Time (hrs)	Perimeter (km)	Length (m)	Width (m)	Max. Depth (m)	Cross Section Area (mouth, m ²)	Mean Tidal Range (m)	Watershed Area (km ²)	Annual W. s. runoff (millions m ³)	June FW Discharge (cms, +/-20.7%)	July FW Discharge (cms, +/- 25.1%)	August FW Discharge (cms, +/- 35.4%)	September FW Discharge (cms, +/- 28.5%)	Loading
Back Cove	Ca	2.2	0.4	4.2	3.1	9	7.6	2,256	1,549	7.6	2,162	2.8	11.3	6.3	0.20	0.46	0.04	0.02	
Bagaduce River	B	15.8	8.0	78.0	35.9	20	56.5	10,881	965	21.3	15,226	3.1	199.9	112.0	4.01	8.97	1.05	0.47	
Batson River	S	0.4	0.1	0.7	0.7	5.0	11.3	2,018	37	1.5	45.5	2.6	29.0	16.0	0.5	1.2	0.1	0.1	
Belfast Bay	M	1.9	1.1	7.0	4.0	15.0	13.0	4,785	287	6.4	2907.8	2.7	236.0	132.0	4.8	10.7	1.3	0.6	
Bideford Pool	S	2.0	0.1	2.5	2.3	5	8.2	1,905	620	5.2	335	2.7	2.3	1.3	0.04	0.09	0.01	0.00	2
Blue Hill Harbor	B	1.5	1.1	6.9	4.0	14	9.5	2,224	1,174	9.1	1,607	3.1	33.1	18.5	0.61	1.39	0.14	0.07	
Boothbay Harbor	M	2.1	2.0	18.7	5.4	36	11.6	1,833	1,063	14.6	12,554	2.7	4.6	2.6	0.08	0.18	0.02	0.01	2
Brave Boat Harbor	S	0.4	0.0	0.6	0.5	4	14.6	1,707	268	0.9	521	2.7	4.2	2.3	0.07	0.16	0.01	0.01	
Cape Neddick Harbor	S	0.3	0.2	1.3	0.7	17	2.9	732	427	9.8	3,587	2.6	27.8	15.6	0.51	1.16	0.12	0.06	2
Cobscook Bay	Co	52.2	37.8	560.0	255.0	20	106.7	11,166	2,896	46.0	25,983	5.7	4.5	2.5	0.08	0.18	0.02	0.01	
Cousins River	Ca	0.5	0.1	0.9	0.9	5.0	16.6	6,584	79	1.5	264.8	2.7	30.0	17.0	0.6	1.3	0.1	0.1	
Damariscotta River	M	26.6	22.2	237.0	65.9	38.0	96.7	25,258	1,097	37.8	21025.0	2.7	266.8	149.0	5.4	12.1	1.4	0.6	
Dyer Bay	B	12.3	9.5	84.9	36.0	22	32.8	8,473	1,778	21.3	22,217	3.3	12.2	6.8	0.22	0.49	0.05	0.03	
Fore River	Ca	5.3	2.8	26.7	11.1	23	26.8	7,473	737	12.2	10,627	2.8	134.9	75.6	2.66	5.97	0.68	0.31	3
Gouldsboro Bay	B	27.2	19.4	183.0	76.3	23	39.4	10,912	2,215	18.9	26,941	3.3	157.5	88.2	3.12	7.01	0.81	0.37	
Harpwell Cove	Ca	2.9	1.0	8.8	5.2	14	18.4	5,669	569	6.7	3,112	2.7	10.6	6.0	0.19	0.43	0.04	0.02	
Harpwell Sound	Ca	15.3	11.9	117.0	36.7	33	41.6	7,813	1,504	32.9	14,161	2.7	11.7	6.6	0.21	0.47	0.05	0.02	
Harraseeket River	Ca	4.6	1.6	11.9	8.2	11	29.1	6,066	1,057	18.9	2,230	2.7	19.3	10.8	0.35	0.80	0.08	0.04	2
Harrington River	E	7.7	1.9	20.8	15.8	9	36.6	7,224	1,168	9.8	15,898	3.5	75.4	42.2	1.45	3.27	0.36	0.17	
Inner Machias Bay	E	28.4	19.3	160.0	90.9	16	41.3	6,340	8,534	15.8	32,529	3.8	2,098	1,170	46.64	102.44	13.95	5.39	
Johns River/Johns Bay	M	5.4	4.5	41.3	13.3	32	24.3	4,240	1,686	20.1	16,332	2.7	14.4	8.1	0.26	0.59	0.06	0.03	
Kennebec	M												24,667	13,800	611.17	1,316.24	210.46	69.21	
Kennebunk River	S	0.2	0.1	0.5	0.4	6	6.0	1,486	130	1.5	274	2.7	146.3	81.9	2.89	6.49	0.74	0.34	
Linekin Bay	M	6.5	6.2	86.8	17.0	57	15.6	4,398	1,297	32.3	19,746	2.7	6.7	3.7	0.12	0.27	0.02	0.01	1
Little Kennebec	E	6.4	5.1	43.3	21.3	18	20.7	5,425	2,083	17.4	10,758	3.7	20.7	11.6	0.38	0.86	0.09	0.05	
Little Machias	E	7.6	5.2	64.9	26.0	24	14.4	3,942	2,357	24.7	36,311	4.1	36.3	20.3	0.68	1.53	0.16	0.08	
Little River	S	0.7	0.1	1.1	1.0	5.4	5.2	1,085	780	2.4	167.2	2.6	112.4	62.9	2.2	4.9	0.6	0.3	2
Maquoit Bay	Ca	10.2	7.3	40.4	23.9	14	23.4	5,903	2,113	7.3	12,425	2.8	16.0	9.0	0.29	0.66	0.07	0.03	2
Medomak	M	13.3	8.5	66.0	30.0	20.5	57.0	8,372	1,869	28.3	8916.8	2.8	282.3	158.0	5.7	12.8	1.5	0.7	
Mere Point	Ca	3.5	1.8	11.8	7.2	13	15.7	5,740	986	6.1	4,563	2.7	5.5	3.1	0.09	0.22	0.02	0.01	2
Middle Bay	Ca	10.4	7.2	49.8	24.3	19	18.6	6,645	1,595	13.7	15,261	2.7	4.0	2.2	0.07	0.16	0.01	0.01	2
New Meadows	Ca	18.2	15.1	194.0	45.2	47	46.1	13,228	1,118	46.9	24,173	2.7	27.6	15.4	0.51	1.15	0.12	0.06	2

Waterbody (n=55)	Region	HW Area (km2)	CD Area (km2)	HW Volume (millions m3)	Tidal Volume (millions m3)	Flushing Time (hrs)	Perimeter (km)	Length (m)	Width (m)	Max. Depth (m)	Cross Section Area (mouth, m2)	Mean Tidal Range (m)	Watershed Area (km2)	Annual W. s. runoff (millions m3)	June FW Discharge (cms, +/-20.7%)	July FW Discharge (cms, +/- 25.1%)	August FW Discharge (cms, +/- 35.4%)	September FW Discharge (cms, +/- 28.5%)	Loading
Pennamaquan River	Co	4.3	2.7	30.7	20.1	12	22.2	4,806	965	14.0	10,244	5.8	140.1	78.5	2.76	6.21	0.71	0.33	
Perkins Cove	S	0.1	0.0	0.2	0.1	11	1.5	645	89	5.8	829	2.6	19.3	10.8	0.35	0.80	0.08	0.04	
Pleasant River	E	8.5	3.4	29.7	19.9	11	41.0	12,476	711	12.2	6,783	3.4	326.3	183.0	6.68	14.90	1.80	0.78	1
Presumpscot Est.	Ca	12.0	2.8	146.0	19.3	6	39.5	6,736	1,910	6.7	1,683	2.8	1,676	938.0	36.88	81.16	10.90	4.27	
Quahog Bay	Ca	7.0	5.9	50.3	17.3	27.5	30.6	4,978	732	21.0	8157.8	2.7	6.7	3.8	0.1	0.3	0.0	0.0	2
Royal Estuary	Ca	2.5	1.5	6.9	5.5	8	31.8	3,688	610	1.5	3,228	2.7	403.9	226.0	8.35	18.58	2.27	0.98	
Saco Bay	S	2.2	1.2	7.3	4.5	13	23.1	6,868	310	7.9	895	2.7	4,403	2,470	101.13	220.81	31.57	11.61	
Scarboro Estuary	S	2.4	0.4	3.6	3.3	5	38.7	4,211	417	2.4	784	2.8	156	145.0	3.08	6.92	0.80	0.36	
Sheepscoot	M												906.5	508.0	19.42	42.95	5.54	2.26	
Sipp Bay	Co	0.8	0.3	3.6	3.2	6	5.1	986	620	3.7	4,340	5.8	4.1	2.3	0.07	0.16	0.01	0.01	
Skillings River	B	10.1	4.7	41.3	23.0	15	52.8	6,309	1,361	13.4	2,503	3.2	91.7	51.3	1.78	4.00	0.44	0.21	
Somes Sound	B	8.1	7.0	116.0	23.5	55	20.8	6,939	894	47.5	6,443	3.1	37.3	20.9	0.69	1.58	0.17	0.08	2
South Bay	Co	14.1	11.0	153.0	73.3	19	40.6	6,289	2,113	18.3	42,663	5.9	2.8	1.6	0.05	0.11	0.01	0.01	
Spruce Creek	S	2.0	0.6	4.5	3.3	10	16.9	3,267	555	6.7	942	2.7	24.3	13.6	0.44	1.01	0.10	0.05	2
Spurwink River	S	0.9	0.3	1.7	1.6	5.0	20.5	6,712	43	1.5	144.0	2.8	25.0	14.0	0.5	1.0	0.1	0.1	
St. Croix Est.	Co	33.8	29.1	547.0	186.0	29.9	66.4	15,138	2,022	42.1	36,463.3	5.9	4,224.3	2,370.0	96.8	211.5	30.2	11.1	
St. George River	M	20.1	12.9	136.0	44.3	31.5	74.2	12,812	772	28.0	14,904.5	2.7	668.2	374.0	14.1	31.3	4.0	1.6	
Taunton Bay	B	13.6	8.0	52.5	34.2	12	46.5	11,227	2,012	23.2	1,208	3.2	157.7	88.3	3.13	7.02	0.81	0.37	2
Union River Bay	B	32.8	30.7	553.0	101.0	62	38.9	10,680	2,359	60.0	77,149	3.2	1,458	817.0	31.90	70.28	9.35	3.70	2
Webhannet River	S	1.0	0.1	1.3	1.2	5	32.3	2,443	224	3.0	474	2.6	36.5	20.5	0.68	1.54	0.16	0.08	
West Bay	B	6.9	3.9	23.1	17.5	9	22.3	4,806	1,179	6.1	8,807	3.3	41.2	23.1	0.77	1.75	0.18	0.09	
Whiting Bay	Co	9.1	5.7	62.9	39.3	13	41.2	6,807	1,057	13.4	13,067	5.4	166.1	93.0	3.30	7.40	0.86	0.39	
York Harbor	S	0.8	0.5	3.3	1.7	17.5	9.1	3,129	269	10.4	3105.8	2.6	83.4	46.7	1.6	3.6	0.4	0.2	

S=So. Me. S
Ca=Casco Bay Ca
M=Mid Me. M
B=B.H./French B
E=East Me. E
Co=Cobscook Bay Co